WALKABILITY, AMENITY, AND PHYSICAL ACTIVITY:

A STUDY OF SALT LAKE COUNTY

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

Walking is regarded as the best moderate to vigorous physical activity (PA), which benefits people's mental and physical health by decreasing obesity, increasing disease control, and relieving depression. Hence, promoting walkability is critical to sustainable development. In this thesis, we analyze the determinants of walkability regarding sociodemographic status, street design, land-use, accessibility to public facilities, and neighborhood safety in Salt Lake County, Utah, United States. A four-component walkability index is employed as a quantitative measurement of street design and land-use the validity of which is tested at various geographic scales. The multiscale test results indicate that current neighborhood design in Salt Lake County only supports people's 20 minute walk. By building multivariable models and spatial regression models, we find that people with high education levels tend to walk more and neighborhoods with compact design are more walkable than others. Neighborhood amenities are further investigated using latent variable modeling and the model result suggests that accessibility to public transportation can help promote walking. Although street connectivity is still a good indicator of walkability, it is less influenced by urban development compared with other walkability indices.

TABLE OF CONTENTS

LIST OF FIGURES

Figures

LIST OF TABLES

Tables

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CHAPTER 1

INTRODUCTION

A high obesity rate has troubled the United States for several decades. Although the increasing rate appears to be slowing, the current obesity rate is over 35%, which is a high level (Ogden, 2012). The rate of adult obesity in Salt Lake County is approximately 25%, much lower than the national average. However, the increasing trend is evident, especially childhood obesity (IBIS, 2011). Figure 1.1 illustrates that the percentage of people suffering from obesity in Salt Lake County keeps increasing in the last 20 years. High obesity prevalence has apparently become a legitimate public health concern in Salt Lake County. Since physical inactivity is widely considered as a major risk factor for obesity (Crespo et al., 2000; Katzmarzyk et al., 2000), increasing physical activity (PA) helps maintain citizens' health. Since human health is a vital factor in analyzing sustainability (Bradley & Kibert, 1998), an urgent need is to promote physical activity in Salt Lake County.

A large body of literature has emerged to address the influence of social status and neighborhood design on PA. The research outcomes suggest that physical inactivity results from the synthesis of sociodemographic status, personal preference, individual behavior, neighborhood design, and genetic factors (Bauman et al., 2012; Brown et al., 2009; Brown et al., 2013; Christian et al., 2003; Frank et al., 2005; Frank et al., 2006; Giles-Corti &

Donovan, 2002; Hagger, Chatzisarantis, & Biddle, 2002; Lee et al., 2005; Salmon et al., 2003). Among all these factors, neighborhood design draws more attention than others, and density, diversity, and design are usually used to measure neighborhood design (Cervero & Kockelman, 1997). Based on these measures, a walkability index is proposed by Frank et al. to measure neighborhood design quantitatively, which is now popular (Frank et al., 2005). However, further investigations emphasize the importance of a context-specific walkability index (Christian et al., 2011; Mayne et al., 2013). Therefore, a context-specific walkability index is required for research on walkability in Salt Lake County.

This thesis has four goals. First, the spatial distribution of people's walking behavior and four walkable indices will be mapped. The spatial autocorrelation of people's walking behavior will be examined and the spatial clusters will be detected by a local indicator of spatial autocorrelation. Then, the effectiveness of these four walkability indices will be tested at different geographical scales to construct a context-specific walkability index. Ordinary least squares (OLS) and the spatial regression models will be applied to explore the insight on relationships between PA, and different kinds of amenities and sociodemographic status. Furthermore, relying on latent variable analysis, accessibility to transportation will be further investigated as an indicator of walkability.

This thesis will begin with a brief literature review that will discuss the background of the study. Then, a walkability index will be introduced as the primary method to measure neighborhood design. The following part will illustrate methods and resources for this study in details. Results will be the next part, and the findings will be discussed. Conclusions will be provided at the end.

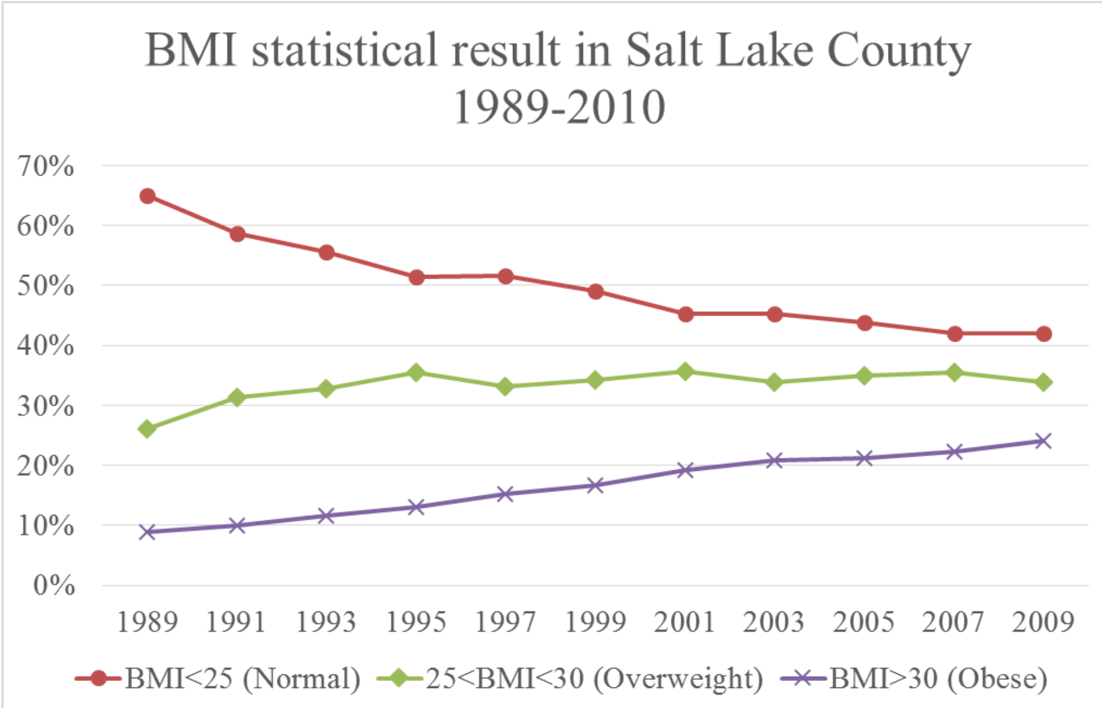

Figure 1.1 BMI in Salt Lake County

CHAPTER 2

LITERATURE REVIEW

2.1 Physical Activity: Benefit, Measurement

Regular PA contributes to a healthy lifestyle and it is defined as any bodily movement produced by skeletal muscles that result in energy expenditure (Casperson, Powell, & Christenson, 1985; Pate et al., 1995). The benefits of PA are well documented such as preventing excessive weight gain (Andersen et al., 1998; Fan et al., 2013a; Frank et al., 2006; Smith et al., 2008; Warburton, Nicol, & Bredin, 2006), improving disease control (Gordon-Larsen, Nelson, Page, & Popkin, 2006; Pate et al., 1985; Powell, Thompson, Caspersen & Kendrick, 1987) and mental health benefits such as reducing the symptoms of depression (Dunn, Trivedi & O'Neal, 2001). Regarding these health benefits of PA, the American College of Sports Medicine and the Centers for Disease Control and Prevention recommends 30 minute of PA (walking and jogging) per day for 18 to 65-year-old healthy adults (Haskell et al., 2007).

Since research on PA has drawn much attention, the priority is to develop a reliable tool to quantify PA (CDC, 1999). Both subjective and objective tools are available to capture PA and subjective tools such as surveys and questionnaires are used more commonly. Much work has employed surveys or questionnaires to capture PA. Baeck, Burema, and Frijters (1985) classify habitual PA into 29 kinds of activities, which concern occupation, movement, sports, PA during leisure time, and sleeping habits. However, these 29 items cannot cover all kinds of PA. Jacob, Ainsworth, Hartman, and Leon (1995) call for a more comprehensive questionnaire about different kinds of PA after reviewing over 10 questionnaires on PA. Walking is treated as a primary type of PA and the "last 7-day recall," which examines walk trips in the last 7 days (Booth et al., 2003), is a good survey tool for research on walkability. Now, there are many sources for survey-based and self-reported measurement of PA, and some of them are published and accessible online (Borowski & Bowles, 2012). Compared with subjective measures, objective measures are more precise and reliable (Ellery et al., 2014). However, the high cost of the technique entailed in collecting objective PA data impedes its wide application. The accelerometer is one of the promising objective tools that has been used in regional PA research and performs well (Brown et al., 2014; Hendelman et al., 2000; Stewart et al., 2000; Troiano et al., 2007). Using both objective and subjective measurements is encouraged in future work (Stewart et al., 2000).

2.2 Determinants of Physical Acitivity

In the United States, one in three adults and four in five adolescents do not meet the levels of PA recommended by public health guidelines (Casperson et al., 2000; Fan et al., 2013b; Hallal et al., 2012; Troiano et al., 2007). The etiology of individuals' participation in PA has drawn much attention. Researchers examine objective factors including sociodemographic status and neighborhood environment, and subjective factors such as personal preference.

Age is one of the most studied demographic factors. Teenagers' participation in PA drastically declines as they grow up and PA participation tends to be stable in young and middle-aged adulthood, then increases a little after middle-age adulthood and declines with old age (Bradley et al., 2011; Caspersen et al., 2000; Wen & Su, 2014a; Zick et al., 2007). Also, gender is another frequent concern while research on PA levels of the world's population suggests that women are more likely to be physical inactive at all ages (Hallal et al., 2012). Furthermore, there are some other concerns that are related to PA such as family structure and race (Crespo et al., 2000; Marshall et al., 2007; Quarmby & Dagkas, 2010). Since sociodemographic factors we mention above are influenced by city development and urban form (Knox & Pinch, 2014; Tratalos et al., 2007; Wirth, 1938), the focus of PA research has gradually moved to the influence of urban form and design.

The relationship between urban form and travel behavior is a key concern of urban planning (Boarnet et al., 2003). In sprawling metropolitan areas with low diversity, low density, and less transportation accessibility, people tend to walk less and weigh more (Ewing et al., 2003) while mixed land-use and public transit are found to facilitate residents' PA (Barton & Crane, 2009). High-level PA is detected in the neighborhoods with highly mixed land-use, high density, and great accessibility to work opportunity (Ewing & Cervero, 2001; Heath et al., 2006; Saelens, Sallis, Black & Chen, 2003). Street design features including street connectivity, street safety, sidewalks, and crosswalks in the neighborhoods have also drawn much attention and the evidence shows that people walk more in a well-connected areas with safe streets (Ewing et al., 2001; Heath et al., 2006; Saelens et al., 2003; Salvo et al., 2014). Urban safety is another concern of urban planning and it was documented that a high prevalence of people's physical inactivity is the result of people's perception of neighborhood unsafety based on a survey (CDC, 1999). Pikora et al. (2003) proposes a framework of how environmental determinants influence PA.

Loukaitou-Sideris (2006) summarized the literature and classified the safety factors into two categories, human (e.g., crime) and nonhuman (e.g., poor roadway infrastructure) factors, which cover most of the safety factors.

Throughout the years, much work has been done on people's perception of neighborhood safety in research on physical activity. Areas being perceived unsafe at night is deemed as a barrier to regular physical activity in the neighborhood (Bennett et al., 2007), and this can also lead to obesity problems (Fish, Ettner, Ang, & Brown, 2010). Molnar, Gortmaker, Bull, and Buka (2002) found that high social disorder (e.g., selling drugs and drinking alcohol) and physical disorder (e.g., tagging graffiti) are associated with moderate physical activity. Social disorder usually leads to an increase in the crime rate that decreases the PA of women and elder adults (Foster & Giles-Corti, 2008). Also, influences from crime-related safety items vary across race (Hooker, Wilson, Griffin, & Ainsworth, 2005) and gender (Humpel, Owen, & Leslie, 2004). In Mota, Almeida, Santos, and Ribeiro's (2005) research, safety factors are not associated with adults' physical activity.

2.3 Physical Activity and Neighborhood Amenity

Since people's PA is related to urban form, scholars have attempted to explore the association between urban amenities and people's PA. Urban amenities can be classified into three categories: natural amenities like hills and rivers, historical amenities generated by buildings and parks, and modern amenities including restaurants and theaters (Bruecker, Thisse, & Zenou, 1999). Nilsson (2014) analyzes the location of natural amenities and finds that neighborhoods with more natural amenities are usually characterized by high population density and housing density, which is highly related to walkability. The spatial distribution of both the exogenous (river, ocean etc.) and endogenous amenities (public service) has been proven to be tightly associated with community characteristics and the urban landscape (Wu, 2006). Moreover, cultural and historical amenities can explain migrant scales (Andersson & Andersson, 2006), and land-use can affect neighborhood's conversion by generating open space and increasing a sprawled pattern of development (Irwin & Bockstael, 2004). Thus, amenities are not negligible in the consideration of the development of urban landscape and neighborhood community.

However, most of the research focuses on parks because there are a large number of parks in some neighborhoods that can provide great resources for PA (Lee et al., 2005). Parks offer a unique setting within the urban landscape, opportunities for PA, and a place for enjoying nature and people's interaction (Hayward & Weitzer, 1984). Cohen et al. (2006) study adolescent school girls and make a conclusion that the girls living near parks are likely to walk more. However, further study shows that parks' features like trails are more likely to influence PA than the distance to parks and park size (Kaczynski, Potwarka, & Saelens, 2008). Another study suggests that the association between PA and parks mostly depends on people's sociodemographic status (Babey, Hastert, Yu, & Brown 2008).

2.4 Walkability Index

The "3 Ds" is one framework to quantitatively measure urban form, which includes population density, pedestrian-friendly design, and diversity of destinations (Brown et al., 2013; Cervero et al., 1997; Ewing et al., 2001; Ewing et al., 2010; Humpel et al., 2002). As transit-oriented development (TOD) is considered as the most sustainable form of urban development (Cervero et al., 2004), two other dimensions are added to the 3 Ds and make up the 5 Ds: *density*, *design*, *diversity*, *distance to transit,* and *destination accessibility*. Distance to transit and destination accessibility emphasized the public transportation accessibility to residents and how easily the neighborhood amenities are accessible (Cervero et al., 2008). All these Ds are aimed at promoting walking (Ellis, 2002).

Based on this framework, the original walkability index is proposed that includes three variables: street connectivity, net residential density, and land-use mix, which separately describes the pedestrian-friendly design, population density, and diversity of neighborhood land-use (Frank et al., 2005). While pedestrian-oriented retail centers are getting popular in urban design, the retail floor area ratio is integrated to achieve a more favorable result by Frank et al. (2005). However, the application of this four-component walkability index is limited for lack of data (Christian et al., 2011; Mayne et al., 2013). Hence, a context-specific walkability index is required for future research (Christian et al., 2011; Mayne et al., 2013). Mayne et al. (2013) test the validity of the abridged walkability index, and the results suggest that an abridged walkability index can explain about 90% of the full walkability index. Likewise, a three-component walkability index developed based on a study in Sweden stresses that future policies concerning the built environment should consider more context-specific factors (Sundquist et al., 2011).

Land-use mix is a key term to urban planners, which is more discussed than the three other factors. For instance, Brown et al. (2008) calculate land-use mix in different ways and argue that walkable land-use relates to healthy weight. However, varying the combination of land-use mix is suggested to affect the strength of the relationship with different types of walking (Christian et al., 2011). Furthermore, the geographical scale is also the key element in calculating land-use mix (Yamada et al., 2012). Although many researchers try to clarify the influence of land-use mix on walkability, the influence of land-use mix largely depends on the trips and study areas (Mayne et al., 2013; Christian et al., 2011).

2.5 Research on Walkability

Research on walkability is characterized by interdisciplinary studies, and the scholars from geography, sociology, urban planning, and public health all have significant contributions. There are also various data resources that provide walkability data such as questionnaires, surveys, and objective measurements like accelerometers. Over 100 studies were inspected and about 40 studies on walkability were manifested in Table 2.1. Most of these studies are implemented in the United States, while some focus on Europe and Canada. Walking trip data is mainly provided by questionnaires and surveys while some objective measures like accelerometers and GPS help data collection. Regression analysis and GIS work as valuable and popular tools to process geospatial data and to explore potential determinants of walkability.

Although survey-based studies have been widely applied in capturing urban form in the dimension of people's preference, in the mature environment of GIS, objective measurements of urban form have emerged (Bennet et al., 2007). Urban form measures like land-use mix and street connectivity are widely accepted as quantitative indictors in walkability research (Frank et al., 2005; Frank et al., 2006, Frank et al., 2010; Lesile et al., 2007; Manaugh et al., 2011; Marshall & El-Geneidy, 2009; Mayne et al., 2013). After inspecting these studies, two limitations are noteworthy. First, walking is a geographical behavior with spatial clustering and variation. However, the spatial effects such as autocorrelation and heterogeneity cannot be reflected and avoided by currently used regression tools. While the context-specific walkability index is discussed, the development of a walkability index related to various geographical scales still remains largely unknown.

Table 2.1 Research on Walkability

Author	Study Site	Data	Method	Findings
Adams et al., 2009	San Diego, CA	Questionnaire	LM	PA is related to GIS measures of neighborhoods.
Babey et al., 2008	California	Survey	LRM	Relationship between PA and accessibility to parks differs depending on adolescents' sociodemographic, housing and neighborhood characteristics
Bennett et al., 2007	Boston, MA	Questionnaire	LRM	Feeling unsafe at night might be a barrier to regular PA, especially for women in poor neighborhoods.
Boer et al., 2007	Ten U.S. Metropolitans	Survey	LRM	High business density and more street intersections are associated with more walking.
Bradley et al., 2011	Ten University Sites in U.S.	Interview	GCM	Boys with more parental transportation to activities, parental encourage, and less parental monitoring has more minutes of PA.
Brown et al., 2014	Salt Lake County, Utah	Accelerometer, GPS loggers	RT	Object measure tools provide a novel way to study PA.
Brown et al., 2009	Salt Lake County, Utah	Driver License Data	GLM	Presence of walkable land-use is associated with healthy weight
Brown et al., 2013	Sixty U.S. geographical area	Accelerometer, Census Tract	LRM	Walking and biking to work are related to lower weight and higher PA.
Carr et al., 2010	Rhode Island	Census Tract	PC	Walk Score is reliable as a measure of estimating access to walkable amenities.
Christian et al., 2011	Western Australian	Questionnaire	LRM	Varying the combination of land-uses in land-use mix calculation of WI affects the strength of relationships with different types of walking
Cohen et al., 2006	Six areas in U.S	Accelerometer	HLM	Adolescent girls living near more park engage in more PA
Crespo et al., 2000	U.S.	Survey	T-test	African-Americans and Mexican-Americans report higher preference of leisure time inactivity than their Caucasian counterparts across social class factors

Table 2.1 continued

Author	Study Site	Data	Method	Findings
Duncan et al., 2010	Adelaide, Australia	Survey	GLM	Get a revised land-use mix score (commercial, industrial and residential)
Duncan et al., 2010	Adelaide, Australia	Survey	GLM	Get a revised land-use mix score (commercial, industrial and residential) which has a stronger association with minutes of walking than the original land-use score.
Ewing et al., 2006	Dozens of Cities in U.S.	Survey	LM	Qualitative urban design qualities like human scale, transparency, enclosure, and imageability are related to walkability
Ewing et al., 2014	15 regions in U.S.	Survey	HLM	Walk trip increase with D variables like activity density, intersections, land-use entropy, transit accessibility to employment; transportation stops density.
Frank et al., 2004	Atlanta, GA	Survey	LM	Gender and ethnicity influence the relationship between urban form and walking distance
Frank et al., 2005	Atlanta, GA	Survey	LM, WI	Proposed a walkability index by a linear combination of dwelling density, street connectivity, and land-use mix.
Frank et al., 2006	Atlanta, GA	Survey	LRM, WI	Walkability index is associated with BMI and walking is related to air quality
Frank et al., 2010	King County, Seattle, WA	Survey	WI	People walk less in low-density and single-use suburban neighborhoods.
Freeman et al., 2012	New York City, NY	Survey	NBRM	Engagement in active travel is associated with neighborhood walkability, especially for non-Hispanic Whites.
Gallimore et al., 2011	Minnesota	Survey	BPC	Children walk more when they live on more walkable routes. Street safety conditions are related to children's preference to walk to school.
Gilderbloom et al., 2015	Louisville, KY	Survey	LM	Walkable areas have high housing values, less prone low crime rates.

Table 2.1 continued

Author	Study Site	Data	Method	Findings
Leslie et al.,, 2005	Adelaide, Australia	Survey	T-test, WI	Walkable neighborhood owns high residential density, street connectivity, and land-use mix except traffic safety and crime safety.
Leslie et al., 2007	Australian	Survey	GIS	GIS data can be used to develop indices of walkability for cities.
Manaugh et al., 2011	Montreal, Canada	Survey	BLM, WI	Walkability index is related to walking trips for non-work trip purpose. Households with more mobility choices are more sensitive to surroundings than those with fewer choices.
Marshall et al., 2009	Vancouver, Canada	Canadian census	LURM, WI	High-walkable neighborhoods own low O_3 concentration and high NO concentration. Neighborhoods with low pollution and high walkability locate near high-income regions.
Mayne et al., 2013	Sydney, Australia	Sydney census	PC, PCA, WI	Abridged walkability index has predictive validity for utilitarian walking.
Meester et al., 2012	Ghent, Belgium	Questionnaire, Accelerometer	HLM	Only in low-SES neighborhoods, neighborhood walkability is positively associated with PA.
Owen et al., 2007	Australia	Survey	LM	Walking for transportation is associated with neighborhood walkability index.
Saelens et al., 2003	San Diego, CA	Survey	LRM	Residents of high-walkability neighborhoods report high residential density, land-use mix, street connectivity, aesthetics, and safety.
Smith et al., 2008	Salt Lake County, UT	Driver licenses	LM	Land-use diversity measures are important predictors of body weight.
Sundquist et al., 2011	Belgium	Questionnaire	HLM	Objective neighborhood walkability works in a Swedish context.
Tucker-Seeley et al., 2009	U.S.	Survey	GLM	Older adults who perceive their neighborhood as safe are more likely to take leisure time PA

Table 2.1 continued

Author	Study Site	Data	Method	Findings
Van et al., 2009	Niklaas, Belgium	Survey	ANOVA	People in higher walkable neighborhoods will take more steps.
Van et al., 2010	Niklaas, Belgium	Survey	HLM	Walkability is positively related to PA.
Wei et al., 2016	Salt Lake County	Survey	LM, SR, WI, GS	The effectiveness of walkability index depends on neighborhood definition, and education is an important indicator of people's walking behavior.
Zick et al., 2007	U.S.	Survey	LRM	Walking is the most common PA among young adults and school children have fewer opportunities to walk to schools.

Table 2.1 Notes: We use the following abbreviations.
BLM: Binary Logit Model
LM: Linear Regression Model
LRM: Logistic Regression Models
SR: Spatial regression
LURM: Land-use Regression Model
GCM: Growth Curved Models
RT: Recall Test
GLM: Generalized Linear Regression Model
PC: Pearson Correlations
PCA: Principle Component Analysis
HLM: Hierarchical Linear Model
GS: Geographical Scale
NBRM: Zero-inflated Negative Binomial Regression Rodel
JM: Joint Model
BPC: Bonferroni Pairwise Comparisons
WI: Walkability Index
GIS: Geography Information Science
RS: Remote Sensing

CHAPTER 3

DATA AND METHODOLOGY

3.1 Study Area and Data Source

The effectiveness of walkability indices is evaluated in Salt Lake County, which covers over 2,000 km^2 and has a population of over 1 million in 2010. This research primarily relies on the Utah Household Travel Survey (UHS), which is a diary-based survey conducted in 2012 by multiple state government agencies and organizations, including Wasatch Front Regional Council, Utah Department of Transportation, and Utah Transit Authorities. This survey took 3 days to record 101,404 biking, driving, and walking trips made by 27,064 individuals living in 9155 households across the state of Utah. People from 2,800 households in Salt Lake County participated in this survey (Tian, Ewing, & Greene, 2015). However, people from only 158 households in Salt Lake County reported their walking trips. The locations of these 158 households are presented in Figure 1.1. The spatial data, including locations of public facilities, road network, and bus and light rail stations, were collected from the Utah Automatic Geographic Reference Center. Additionally, the land-use data at the parcel level were from Salt Lake County 2012 tax assessor's computer-assisted mass appraised (CAMA) data.

3.2 Statistical Methods

OLS is firstly used to examine the relationship between peoples' walking minutes, and the four-component walkability index, transportation, amenity, and socioeconomic status. In this research, three OLS models are applied, which separately examine the influence of sociodemographic status, walkability indices, and neighborhood amenities. However, people's walking behaviors depends on neighborhood environmental factors such as land-use, transportation, and amenity (Frank et al., 2005; Lee et al., 2015), and the time of walk trips is highly spatially autocorrelated. Spatial autocorrelation is revealed by Moran's I as the value is 0.26 with statistical significance. Given that ignoring the spatial autocorrelation could cause biases and inconsistent estimates of the regression coefficients (Anselin, 2009), spatial filtering regression model will be implemented as follows

$$Y = X^{*}\beta + L_X \Gamma + e \qquad \text{(Eq. 1)}$$

X* is the independent variable free from any spatial pattern and β is its coefficient. L_X contains all the spatial pattern and is controlled for the spatial autocorrelation in Y. This regression model removes spatial autocorrelation from residuals and allows for suitable estimated coefficients for independent variables. Furthermore, the spatial term in this model is straightforward to clarify the relationship between spatial dependency and people's walking behavior.

Other than spatial autocorrelation, spatial heterogeneity is the other type of spatial effect in analyzing spatial data. Spatial heterogeneity is usually defined as spatial or regional differentiation, which follows from the intrinsic uniqueness of each location (Anselin, 1988a). To capture the spatially varying relationship between people's walking behavior and these explanatory variables, geographically weighted regression (GWR) is employed. GWR creates a local regression model for each specified geographical region. The kernel function is the most common way to define the geographical region and the regression result is sensitive to the kernel bandwidth. Fotheringham et al. (2002) compared different kinds of kernel function methods and found that fix kernel makes for good prediction when a dataset contains few points within a certain distance. When the points are sparsely distributed over large distances, adaptive bandwidth usually provides more accurate prediction. Coefficient variance (CV) is used to find the adapted bandwidth for the location of households. The regression equation is presented as follows (Eq. 2) (Fotheringham, Brunsdon & Charlton, 2002).

$$Y_i = C_i + \sum_k \beta_{ki} X_{ki} + \varepsilon_i \qquad \text{(Eq. 2)}$$

where Y_i is people's walking minutes to be regressed, C_i is constant, β_{ki} is the parameter for individual explanatory variable, and X_{ki} *(k=1, 2, 3… n),* ε_i is the error term. This model considers the spatial heterogeneity and manifests the complex local variation of regression parameters. By using the GWR model, it is easier to achieve a better understanding of the determinants and their influence.

3.3 Latent Variable Analysis

The latent variable analysis encompasses several specific methods such as factor analysis, path analysis and structural equation modeling (SEM) (Muthén, 2004). This model can analyze the unobserved concept (latent variables) based on the hypothesis and relate one set of observed variables to one set of unobserved variables. Only the variables correlated with each other can construct the latent concept. In the research on transportation, the latent variable analysis is broadly used in the travel demand model to detect unobserved factors like people's attitude and perception (Eboli & Mazzulla, 2007; Yanez, Raveau, & Ortuzar, 2010). Furthermore, several studies use SEM to explore the relationship between neighborhood environment and travel behavior (Bagley et al., 2002; Cao, Mokhtarian, & Handy, 2007; Van Acker, Witlox, & Van Bee, 2007). Since the neighborhood environmental factors are usually related to each other, SEM is more useful than regression analysis here (Van Acker et al., 2007).

There are two steps to implement latent variable analysis. First, confirmatory factor analysis (CFA) determines whether the hypothesized structure provides an excellent fit to the data (Child, 1990). Based on the existing theories (Ewing et al., 2001; Frank et al., 2004; Frank et al., 2005; Heath et al., 2012; Pikora et al., 2003; Saelens et al., 2003), neighborhood environment and sociodemographic status are hypothesized as two latent variables. Several kinds of structures will be examined to achieve the best structural model. After getting the best structure, the structural equation model is employed to explore the relationship between observed variables and latent variables. All the strategies are implemented by R that is a free environment for statistical analysis and graphics.

3.4 Measures

The previous studies on PA select the average of an individual's walking minutes as the dependent variable to measure walking behavior (Brown et al., 2009; Christian et al., 2011; Frank et al., 2005). In this research, trip-level data are aggregated into household level and all the independent variables are calculated by household.

With the records of people's walking trips, the frequency of walking every week, and the household size, the average value of people's walking minutes for each household can be estimated and further used as the dependent variable. Because the dependent variable is skewed, the natural log transformation is used to achieve a continuous dependent variable with approximate normal distribution. We classify the independent variables into several categories: accessibility to transportation, amenities, sociodemographic conditions (household level), land-use and walkability index, and safety factors (Table 3.1). Transportation, amenities, land-use factors, and walkability index are calculated using ArcGIS, the most popular commercial GIS software, and Python, an open-source programming language.

Sociodemographic conditions like age, gender, and race are well documented to influence people's walking behavior (Bradley et al., 2011; Caspersen et al., 2000; Crespo et al., 2000; Marshal et al., 2007; Quarmby et al., 2010; Wen et al., 2014a; Zick et al., 2007). However, this survey misses the information about race and gender. Thus, age is the primary concern in this research. Furthermore, education level is added since previous research suggests that well-educated people tend to walk more (Heath et al., 2012). Variables concerning family conditions are also taken into consideration. People with vehicles tend to walk less, and percentage of adult workers and household income are related to people's walking behavior (Frank et al., 2010; Sallis & Owen, 2000).

Based on the previous studies (Cervero, 1997; Ewing et al., 2001), neighborhoods with high density, high diversity, and well-connected streets are expected to be walkable. To understand how neighborhood environment influences people's walking behavior, walkability index is employed to capture density, diversity, and street design of the neighborhood. For further investigation, some other variables regarding urban design and neighborhood environment are added to models like accessibility to parks. Although some studies have shown that good accessibility to parks does not promote walking (Kaczynski et al., 2008), parks still provide resources for walking, which cannot be ignored (Hayward & Weitzer, 1984).

Transit-oriented development (TOD) is popular in the 21st century, which aims to improve the walkability of the areas near public transportation stations (Cervero, 2004). Hence, accessibility to public transportation promotes walking (Cervero, Murphy, Ferrell, & Goguts, 2004). In this thesis, the distances to bus and light rail stations are included as measures of public transportation. Safety factors are also necessary since people's perception of neighborhood safety influences people's preference to walk (Bennett et al., 2007; Hooker et al., 2005). High crime rate usually leads to high social disorder, which has negtative association with moderate physical activity (Molnar et al., 2002). The bike lane is also an important measurement of street safety (Hoehner et al., 2005). As the main part of Salt Lake Valley, Salt Lake County has some unique factors on walkability, such as earthquake potential, slope and elevation. In this thesis, slope is employed as a measure of terrain, which is also associated with landslides that makes people feel unsafe (Bathrellos Kalivas, & Skilodimou, 2009). Therefore, four safety factors are taken to measure urban safety: crime rate, bike lane coverage, slope, and earthquake potential.

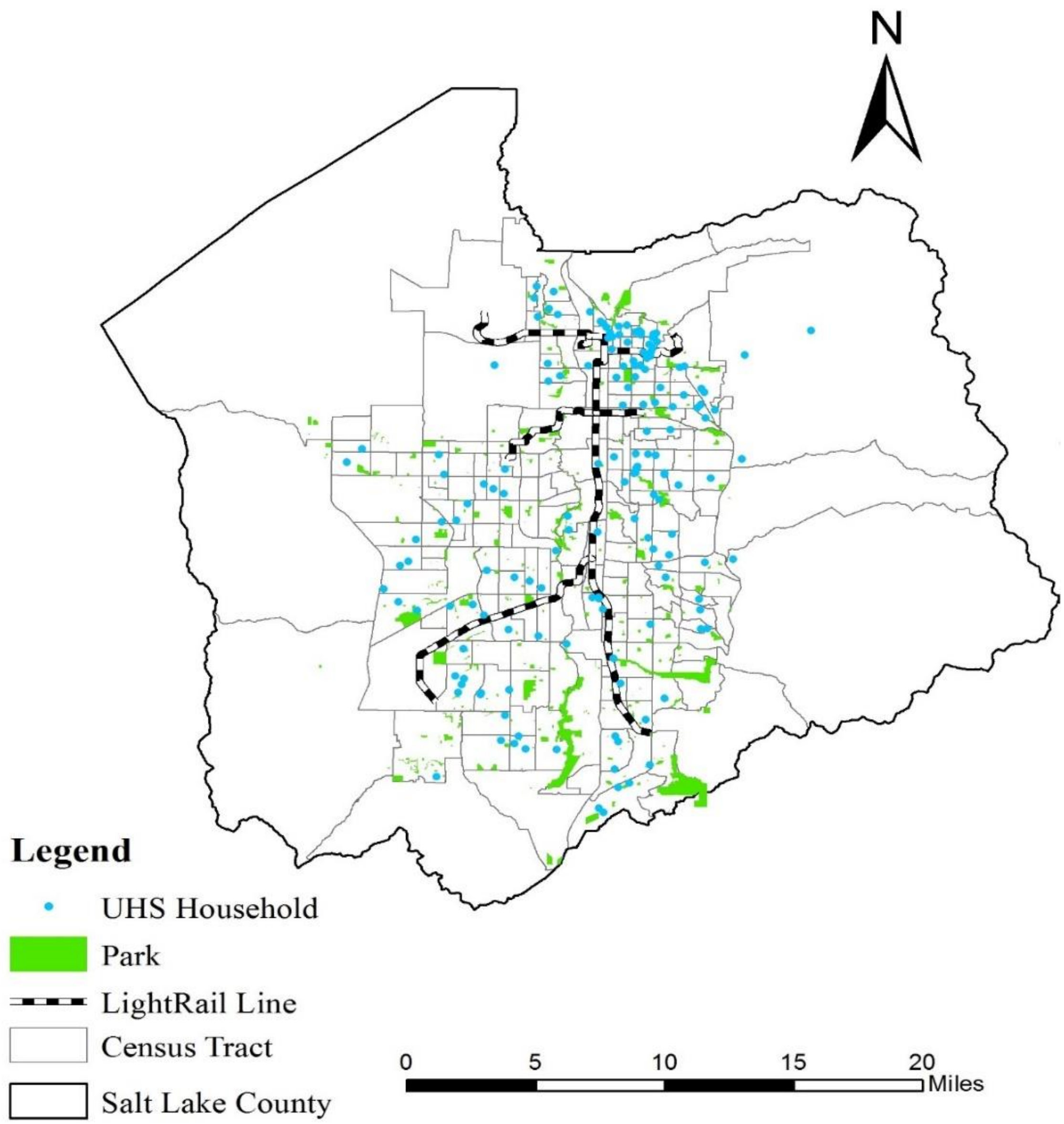

Figure 3.1 Study Area

Table 3.1 Definition of Variables

Dependent Variables	**Description**
PA	Ln (Average time of people's walking trips)
Predictor Variables	**Description**
Sociodemographic Conditions (SC)	Average Age
	Average Education level
	Vehicles per person
	Percentage of adult workers
	Average Household Income (4-caterogry data)
Land-use and Walkability Index	Dwelling Density
	Street Connectivity
	Land-Use Mix
	Retail Floor Area Ratio
Accessibility	Ln (Distance to closest bus station)
	Ln (Distance to closest light rail station)
Public Facility	Ln (Distance to closest park)
	Ln (Distance to closest worship (religious region))
Neighborhood safety	Crime index
	Bike and coverage
	Slope
	Earthquake potential

CHAPTER 4

WALKBILITY INDEX AND PHYSICAL ACTIVITY

Walkability is initially operationalized as a composite of four environmental attributes within the neighborhood area, which is defined by the road network buffer with specified bandwidth. The land use data and transportation data are employed to calcuated these four variables.

To calculate dwelling density, residential parcels within the buffer area are selected and then the total area of the selected parcels and the total number of dwelling units are summarized. Dwelling density is finally calculated by dividing the number of dwelling units by the total area of residential parcels within the neighborhood. The high dwelling density not only improves the accessibility of complementary activities but also compresses the living space (Leslie et al., 2007).

Street connectivity is measured by the number of intersections per square kilometer within the network buffer. Only the intersections with three or more different intersecting streets are included in the street connectivity calculation.

Land-use mix is used to evaluate the evenness in the distribution of land-use. If the land-use is evenly distributed in the network buffer, the value of land-use mix would be 1. If there is only one type of land-use in the network buffer, the value would be 0. The method to calculate land-use mix, and the relationship between land-use mix and walkability, are well discussed by Christian et al. (2011). The land-use mix described in this paper is calculated by four land-use types: residential, commercial, and recreational.

The parcels in commercial use are used to calculate the retail floor area ratio. Salt Lake County 2012 tax assessor's computer-assisted mass appraisal (CAMA) database provides the ground floor area for each parcel. Retail floor area ratio is the total ground floor area divided by the total commercial area in the household network buffer. High retail floor area ratio means more optional destinations for shopping and more local employed opportunities within the walking distance (Leslie et al., 2007). While the parking space is compressed, walking is more encouraged as a trip mode.

While selecting a proper geographic scale is discussed in the previous studies, little thought is given regarding how or why these geographical scales should be selected to define neighborhood areas (Root, 2012). The importance of geographical scale and multilevel approaches are also emphasized in PA research (Saelens et al., 2003; Sallis et al., 1999; Spence & Lee, 2003). Yamada et al. (2012) have employed three different geographical scales, 1-km network buffer, block group, and census track, to demonstrate that different geographical scales could lead to different walkability measures. Moudon et al. (2006) have employed four scales of the neighborhood to identify walkable neighborhoods. Schlossberg and Brown (2004) also have studied the relationship between walkability indicators and transit-oriented development at two geographical scales (0.25 mile and 0.5 miles). Since this research aims to create a context-specific walkability index, multi-scale tests on the performance of these four components are conducted to explain PA. A variety of bandwidths is used to buffer the road network, including 400 m (5-min walk), 600 m, 800 m (10-min walk), 1000 m, 1200 m (15-min walk), 1500 m, 1600 m (20-

min walk), and 1700 m. The OLS model is used to examine the relationship between walkability index and walking minutes with different bandwidths. The results are presented in Figures 4.1 and 4.2.

Figure 4.1 shows the significance of each component. The significances of dwelling density, street connectivity, and retail floor area ratio decrease dramatically when the bandwidth of the network buffer reaches about 1600 m. The R^2 also experiences a rapid decline around 1600 m, implying that the neighborhood environments, including street connectivity, commercial land-use, and population density, do not affect people's walking trips beyond 1600 m. In other words, the neighborhood environments only affect walk trips within 20-min walking distance in Salt Lake County, and longer trips usually depend on some other factors, such as self-selection. In fact, according to Root's research on geographic scale, in many U.S. urban areas, people routinely travel 5 to 10 miles to carry out many daily activities, such as shopping, taking children to school, or exercising (2012). According to the trip records, the average walking time is about half an hour for each person per day. Comparatively, Salt Lake County is now at a low walkability level, and the future development of neighborhood environments is promising to improve walkability.

Another interesting point is that the land-use mix is not significant at any geographical level. The spatial distribution of land-use mix is displayed in Figure 4.3. Figure 4.4 shows the spatial clusters of physical activities in Salt Lake County using the local indicator of spatial autocorrelation (LISA). Clearly, the clusters of high physical activities are not consistent with those of large land-use mix, suggesting that land-use mix is not a good indicator of PA, and the relationship between land-use mix and PA is not linear. Research in Salt Lake County and Australia reveal that the smooth mixture of land-use does not necessarily lead to better walkability. The performance of land-use mix is mainly affected by the land-use category, the type of walking, and the unique conditions of study area (Brown et al., 2009; Christian et al., 2011).

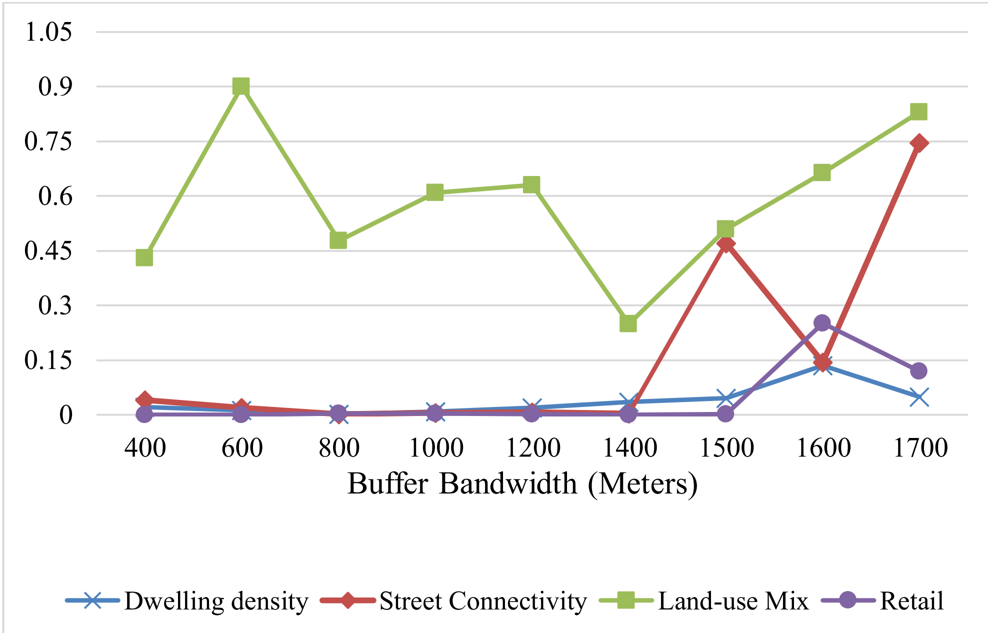

Figure 4.1 The Result of the Multiscale Test (*p*-value)

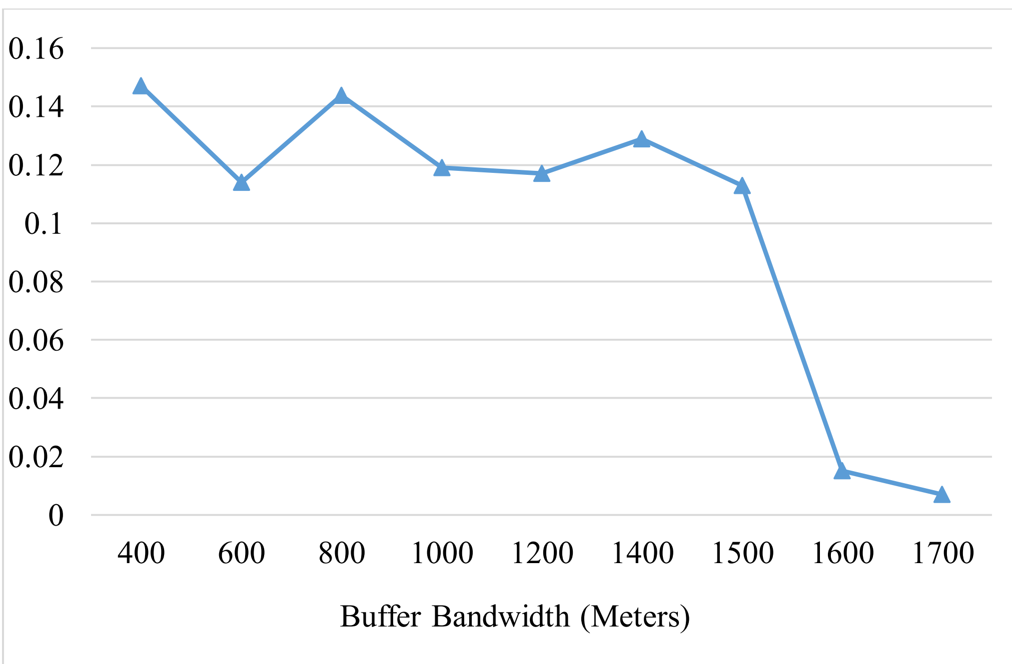

Figure 4.2 The Result of the Multiscale Test (R^2)

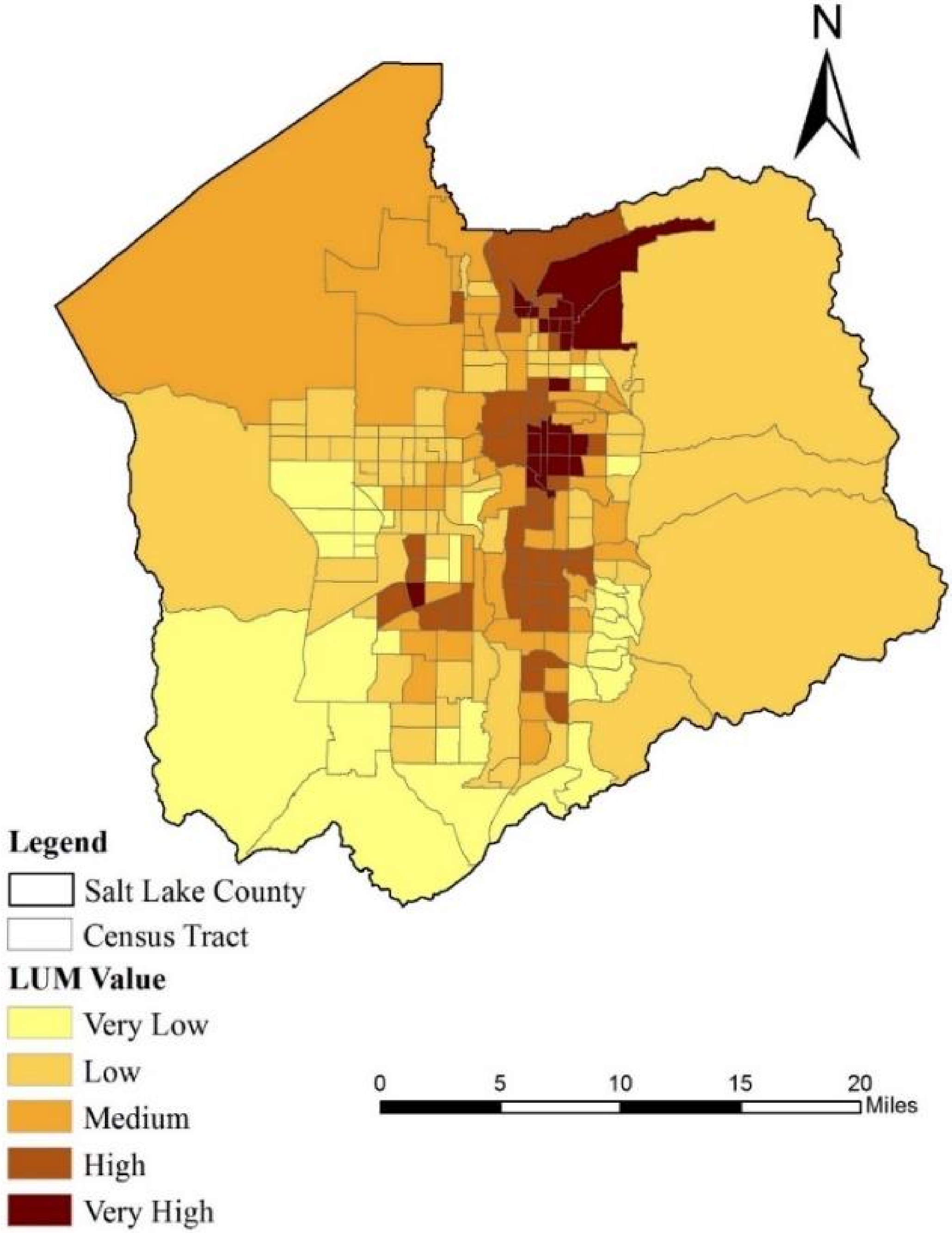

Figure 4.3 Spatial Distribution of Land-use Mix (LUM) in Salt Lake County

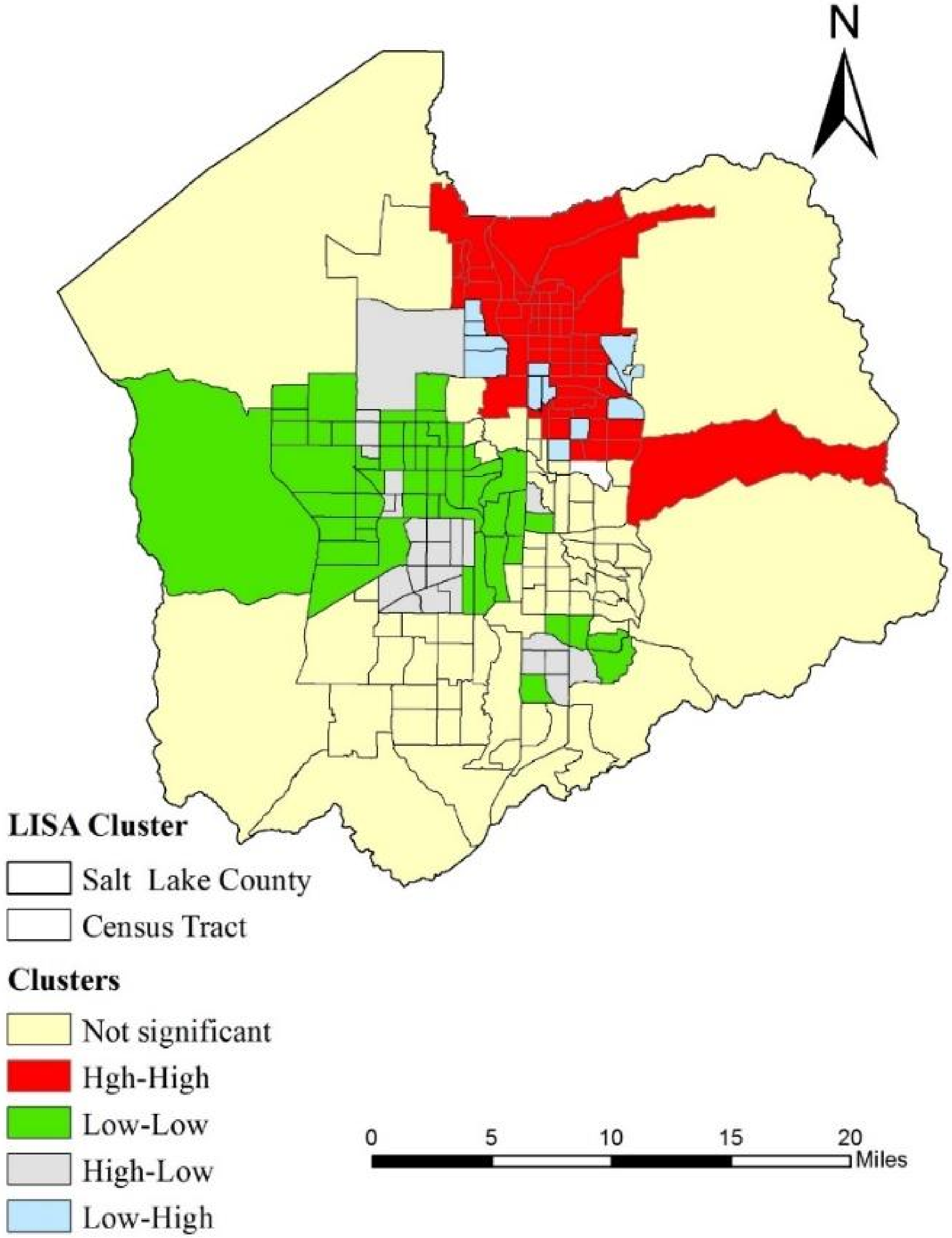

Figure 4.4 Spatial Clusters of PA in Salt Lake County

CHAPTER 5

RESULT OF STATISTICAL AND SPATIAL ANALYSIS

Based on the results of the multiscale analysis, the neighborhood is defined by the 800-m road network buffer. Several linear regression models are employed to examine the determinants of the PA in Salt Lake County, and the results are presented in Table 5.1. Model 1 includes sociodemographic status variables; Model 2 includes original walkability indices and Model 3 includes the amenity variables (e.g. accessibility, public facility, and neighborhood safety). The results of variance inflation factor (VIF) test for all the variables are below 5, which indicate that there is no alarming multicollinearity issue in these model. Akaike's Information Criterion (AIC) is employed to compare models' goodness-of-fit.

Model 2 suggests that the original walkability index can explain 16.6% of the variance of the dependent variable. So the original walkability indices are effective in Salt Lake County. Among these four factors, dwelling density and retail floor area ratio show great significance and both contribute positively to the PA. This result illustrates that high population density leads to walkable communities. The commercial land is also a major factor in promoting walkability, and thus, the compact design of the commercial land could help improve neighborhood walkability.

Figure 5.1 and Figure 5.2 shows, the spatial distribution of the dwelling density and retail floor area ratio. There are many similarities of their spatial distributions in Salt Lake

County. Regions with high dwelling density concentrate around the downtown and university areas while these regions also possess high retail floor area ratio.

Model 1 only contains sociodemographic status variables. This model explains 36.3% of total variance, which is much higher than the two other models. Among these sociodemographic factors, age, and education level are significant. Age has a positive effect on walkability, and the young families tend to walk less than comparatively older families. Education level is the most significant determinant in this model illustrating, the fact that well-educated people walk more, which confirms the importance of education in promoting walkability (Heath et al., 2012).

The third model covers some amenity variables, and this model can explain 14% of total variance. This number is similar to Model 1, which includes the four walkability indices. Since the literature discusses a lot about the limitation of walkability index (Christian et al., 2011; Mayne et al., 2013), the variables in Model 3 would help constructing a better walkability index in future. In this model, crime index is the only significant variable, and the coefficient is positive.

The spatial filtering model is employed to account for spatial dependence, and the results are presented in Table 5.2. A linear regression model is also used for comparison. The R^2 is improved from 0.45 to 0.51, which is a significant improvement. AIC also decreases after the spatial dependency variables are added. This result proves that spatial dependence exists in people's walking behavior in Salt Lake County. Moreover, distance to park is significant in the spatial filtering model, which suggests that ignoring spatial dependence would contribute a biased result for OLS model. Checking the coefficients and their significance, distance to worship becomes significant. This coefficient suggests that the neighborhoods closed to religious regions are less walkable.

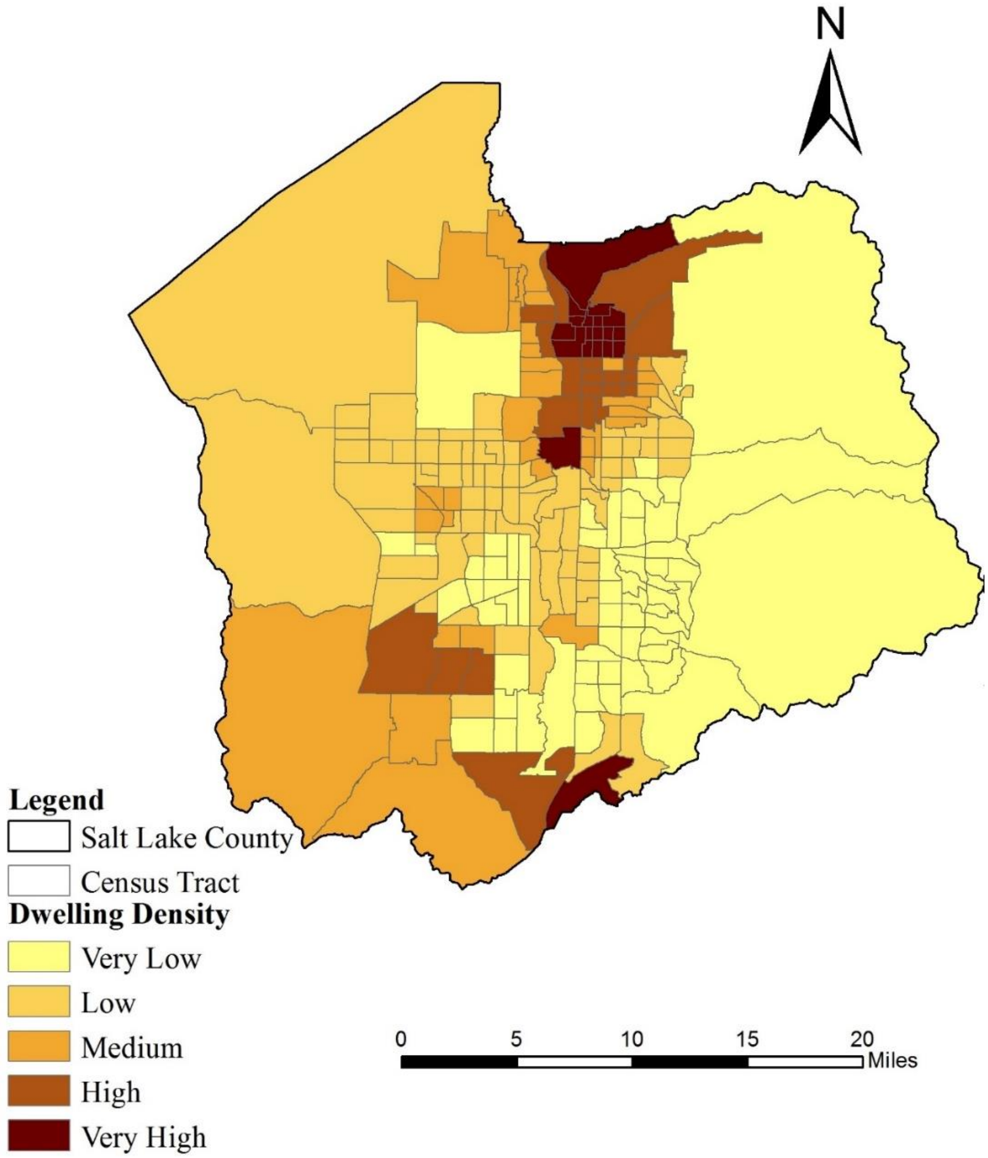

Figure 5.1 Spatial Distribution of Dwelling Density in Salt Lake City

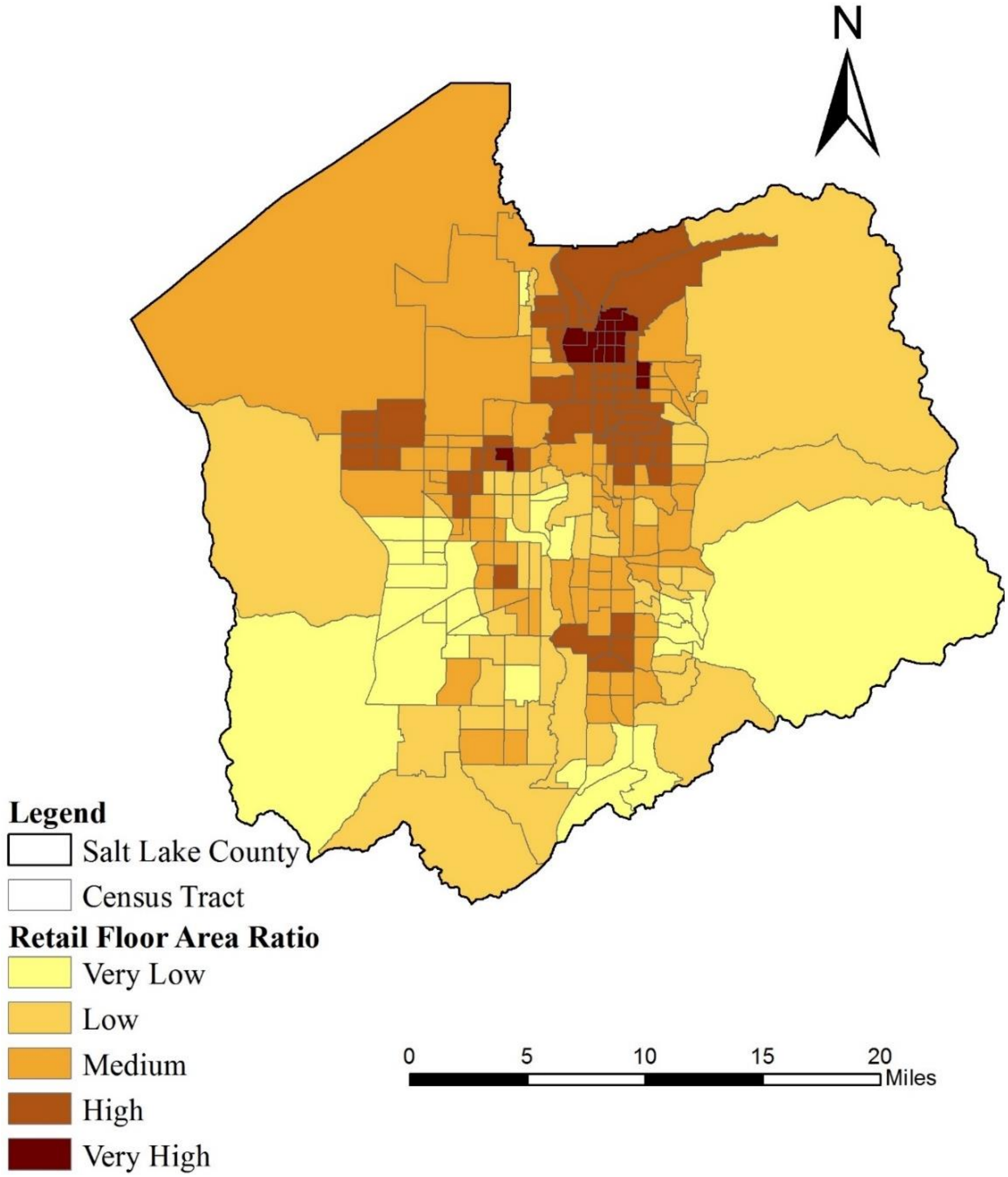

Figure 5.2 Spatial Distribution of Retail Floor Area Ratio in Salt Lake County

Table 5.1 OLS Model Results

Variable	Coefficient		
	Model 1	**Model 2**	**Model 3**
		Sociodemograohic status	
Average AGE	0.003	/	/
Average education level	1.037***	/	/
Vehicles per person	0.063	/	/
Percentage of adult worker	0.197	/	/
Household income	-0.034	/	/
		Land-use	
Dwelling density	/	2094.5**	/
Street connectivity	/	-8370.1**	/
Land-use mix	/	-0.1002	/
Retail floor area	/	17.91**	/
		Accessibility	
Distance to bus stop	/	/	-0.013
Distance to light rail stop	/	/	-0.226
		Public facility	
Distance to park	/	/	-0.184
Distance to worship	/	/	0.200
		Neighborhood safety	
Crime index	/	/	0.001*
Bike lane coverage	/	/	-0.002
Slope	/	/	-0.003
Earthquake Potential	/	/	-0.129
		Assessment	
R^2	0.363	0.166	0.140
AIC	219.01	259.77	270.96

Note: *** Significant at 0.01 level; ** Significant at 0.05 level; * Significant at 0.1 level.

Table 5.2 OLS Model and Spatial Regression Model Results

Variable	**Coefficient**	
	OLS Linear Regression Model	**Spatial Filtering model**
	Sociodemographic status	
Average AGE	0.005 *	0.005 *
Average education level	0.759 ***	0.758 ***
Vehicles per person	−0.146	0.149
Percentage of adult worker	0.232	0.231
Household income	−0.037	−0.037
	Land-use and walkability	
Dwelling density	1411*	1420 *
Street connectivity	−3433	−3501
Land-use mix	−0.121	−0.131
Retail floor area	11.59 *	11.59 *
	Accessibility	
Distance to bus stop	−0.047	−0.063
Distance to light rail stop	−0.035	−0.081
	Public facility	
Distance to park	−0.152	−0.196*
Distance to worship	0.232 *	0.208 *
	Neighborhood safety	
Crime index	0.004	0.004
Bike lane coverage	-0.187	-0.189
Slope	-0.037	-0.37*
Earthquake Potential	-0.092	-0.092
	Assessment	
R^2	0.4544	0.5144
AIC	216.86	210.85

Note: *** Significant at 0.01 level; ** Significant at 0.05 level; * Significant at 0.1 level.

CHAPTER 6

LATENT VARIABLE ANALYSIS

The results from regression analysis suggest that neighborhood environment variables can explain over 14% variance of walkability (Table 5.1, Model 3). However, few of them are significant because they are correlated in the regression model. Obviously, only the four original walkability indices are not enough to measure people's walking behavior in Salt Lake County in this research. Since the urban form has changed a lot after this index was proposed and Salt Lake County is a fast developing region, the walkability index should be improved.

Although the transportation and public facility accessibility are emphasized (Cervero et al., 2004), current research on walkability does not pay much attention to the distance to transit and destination accessibility. In this thesis, some variables based on distance to transit (distance to bus station, distance to rail station) and destination accessibility (distance to park, distance to worship) are incorporated. To figure out whether these variables are suitable to make up a better walkability measure system, latent variables analysis is employed.

6.1 Confirmatory Factor Analysis

Based on the preliminary result above, it is hypothesized that people's walking behavior is influenced by two latent concepts: neighborhood environment and sociodemographic status. Neighborhood environment is controlled by dwelling density, street connectivity, land-use mix, retail floor area ratio, distance to bus stop, distance to rail stop, distance to worship, and distance to park. However, not all these eight variables are suitable for modeling. Thus, confirmatory factor analysis (CFA) is employed to validate the effectiveness of these models before model estimating. Several model structures are tested, and the best fitted one will be chosen for further analysis (Table 6.1). Table 6.2 shows model results.

6.2 Result of Structural Equation Modeling

The model results suggest that model CFA2 is the best model to control for neighborhood environment, which includes dwelling density, land-use mix, retail floor area, distance to rail station, and distance to bus station. While education level, vehicle per person, and percentage of adult workers are employed to control for sociodemographic status, the structure equation modeling result is presented in Figure 6.1.

In the regression analysis, land-use mix is not a significant indicator of walkability while the street connectivity shows significance (Tale 2, Model 2). However, in structural equation modeling, adding street connectivity decreases the model fitness. After checking these five selected variables, they are all largely influenced by urban development, including population growth, building public transportation system, and changing land-use.

Street connectivity is calculated by street intersections divided by the area of the buffer. Since Salt Lake County is one of the metropolitan regions in U.S., the street system remains unchanged for several years. However, population density has changed a lot. From 1980 to 2010, the population increased from 0.6 million to 1.2 million. As population increased in Salt Lake County, the public transportation system is also much improved by the bus rapid transit system and light rail system (TRAX). Also, modern shopping malls are constructed in Salt Lake County such as City Creek Center (2012) with mixed land-use. Although the influence from street connectivity on walkability should not be overlooked, street connectivity should be separately considered while it is less influence by urban development.

After adding two transportation factors, neighborhood environment is significant as a latent variable. This model result emphasizes the importance of the public transportation system in current urban research. By checking the coefficients, we can see that the accessibility to public transportation stops can improve walkability. In the United States, transit-oriented development has gained currency for helping promote smart growth (Cervero et al., 2004) and walking (Schlossberg & Brown, 2004). Therefore, accessibility to public transit system would play a larger role in future research on walkability.

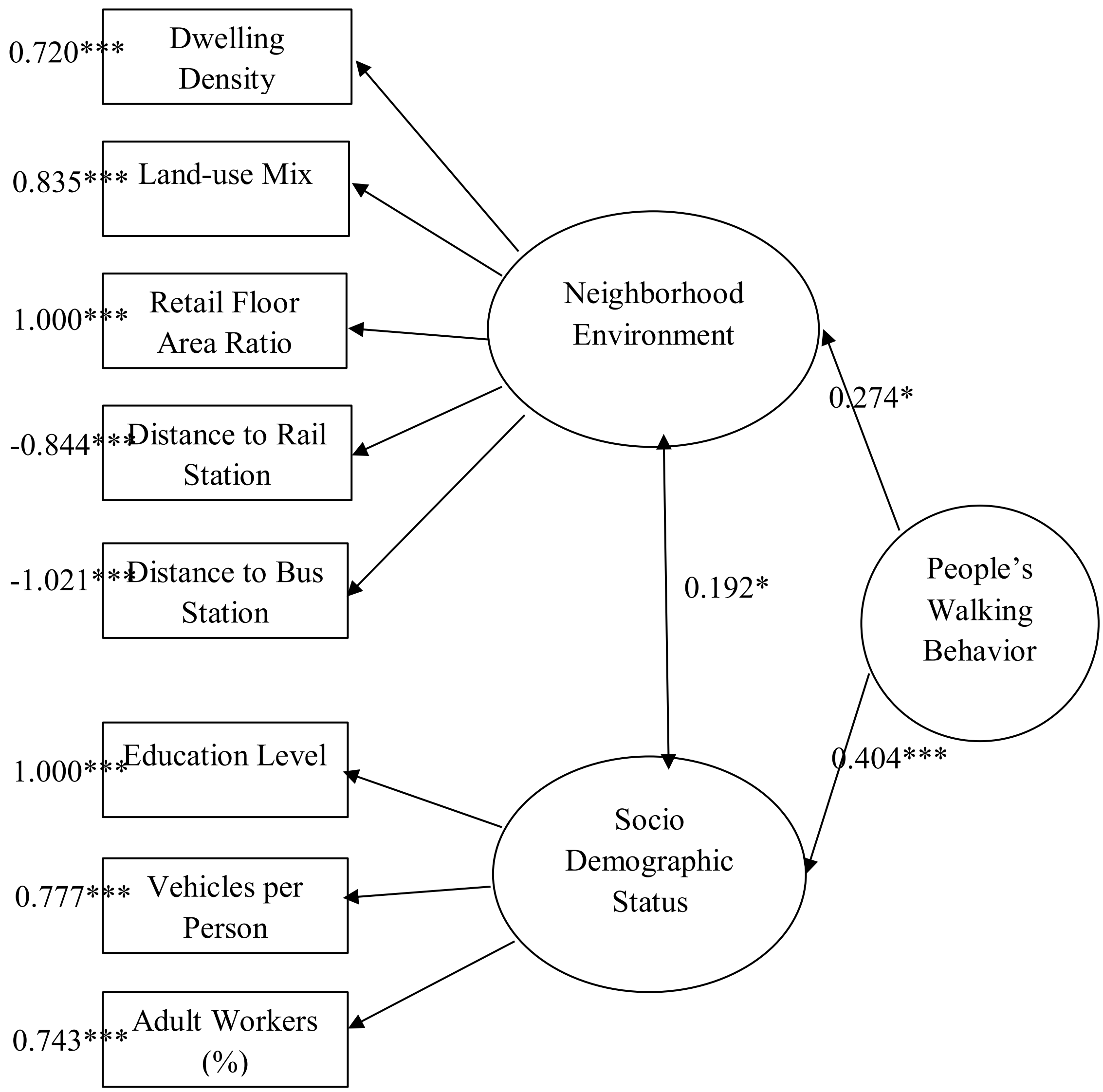

Figure 6.1 Structure Equation Model Result

Note: *** Significant at 0.01 level; ** Significant at 0.05 level; * Significant at 0.1 level.

Table 6.1 CFA Models

	Dwelling	**Land-use**	**Intersection**	**Retail**	**Park**	**Worship**	**Rail**	**Bus**
CFA1	√	√	√	√				
CFA2	√	√		√			√	√
CFA3	√	√				√	√	√
CFA4	√	√		√	√		√	√

Table 6.2 CFA Model Results

	$\chi 2$/df	CFI	TLI	RMSEA
CFA1	3.830	0.836	0.735	0.134
CFA2	**1.535**	**0.967**	**0.951**	**0.058**
CFA3	2.202	0.919	0.887	0.087
CFA4	2.390	0.915	0.862	0.096

Note: CFI: Comparative Fit Index; TLI: Tucker-Lewis Index; RMSEA: Root-mean-square error of approximation. CFI value over 0.95, TLI value over 0.90 and RMSEA below 0.08 indicate a relatively good fit model.

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CHAPTER 7

DISCUSSION

As we discussed in the literature review, little work has been done to examine the impacts of geographical scales on the effectiveness of the walkability index. The 800-m road network buffer is usually considered to be the best choice to define the neighborhood (Frank et al., 2005; Manaugh et al., 2001). However, the underlying reasons for the selection of this bandwidth are less discussed. This paper tests the performance of the four walkability indices, confirms the validity of the 800-meter bandwidth, and finds the threshold for defining neighborhood (1600-m network buffer). This threshold also indicates that neighborhood environment in Salt Lake County can only support people's 1600-m walking in Salt Lake County. On average, it is estimated that the 800-m walk takes 10 min, and the 1600-m walk takes 20 min. However, 30-min moderate-intensity PA for at least 5 days each week is recommended for adults (Baeche et al., 1982; Haskell et al., 2007) and 60 min for youths (Strong et al., 2005). Hence, most of the current neighborhood designs are not sufficient to facilitate communities residents to meet the PA recommendation.

This study employs the four-component walkability index to explore people's walking behavior in Salt Lake County. With the neighborhood is defined by an 800-m network buffer, these four walkability indices can explain about 16.6% variance of PA. The walkability index's contribution to the variance of PA is larger than what is reported in similar research conducted in Atlanta and King County, Washington, wherein it respectively explains 10.7% and 8.3% variance of people's walking behavior (Frank et al., 2005; Frank et al., 2006). Hence, people's walking behavior relies on neighborhood design more significantly in Salt Lake County. But the neighborhood design still cannot meet the general requirement of at least 30 min moderate-vigorous PA. Improving the density of the neighborhood will play a significant role in promoting walking.

As the urban sprawl phenomenon is looming large in the United States, population density and land-use diversity are emphasized by policy makers because the compact city with medium-high density housing can benefit sustainable development of the city (Ancell & Thompson-Fawcett, 2008). Numerous studies have documented that increasing the density can decrease vehicle mile of travel (VMT) and create short trips (Cervero et al., 1997; Ewing et al., 2001; Frank et al., 2006). The generated short trips will make people walk more in the neighborhoods. In the southwestern area of Salt Lake County, the density is relatively low. The government and policymakers should pay more attention to increase the density in these areas. The other way to generate short walk trips is to improve the accessibility to public transportation (Schlossberg et al., 2004). With the fast development, Salt Lake County experiences a rapid growth in population, change in urban land-use, and development in public transportation. In the latent variable analysis, the unobserved variables related to neighborhood environment are all influenced by rapid development in Salt Lake County. Thus, the accessibility to public transportation will be a promising measurement of walkability regarding urban development. Hence, in future research, public transportation should be taken into consideration.

Among the four traditional walkability indices, the land-use mix is not significant at various geographical scales in this research. One reason is that the relationship between land-use mix and PA depends on the study area and trip type. After checking the destinations of the 490 trips taken by the 158 households, we find that over 200 trips are for exercising or walking with the dog. These trips are less likely to be affected by the mix-used land and are more likely to be influenced by neighborhood density, personal preference, and sociodemographic status. Another reason might be that Salt Lake County is now at low mix land-use level. The 2800 households covering the entire Salt Lake County are taken to calculate the four-category land-use mix. The average value of land-use mix in Salt Lake County is 0.22, while the land-use mix values are 0.31 in King County and 0.38 in Atlanta (Frank et al., 2005; Frank et al., 2006). Compared to these two well-developed regions, the mixed use is relatively low in Salt Lake County.

Other than traditional walkability index and sociodemographic status, the regression analysis also suggests that distance to worship, crime index, and slope are related to people's walking behavior. In Salt Lake County, crime index contributes to walkability based on the result of regressions, which is opposite to logical thinking. In fact, a lot of literature provides the evidence that people tend to walk more when the crime rate decreases (Foster et al., 2008; Humpel et al., 2004; McDonald , 2008). These studies above focus on the influence of crime rate on walkability and do not discuss how the neighborhood environment affects the crime rate. When walkability increases, sidewalks and well-connected streets sometimes lead to a high crash rate and crime rate (Zhu et al., 2008). Although the crime rate is only significant in Model 3 (Table 5.1), the policymakers also need to consider the safety outcomes while improving the neighborhood environments to promote walking. In the full OLS model, the estimated coefficients suggest that worship negatively influences its neighborhood walkability. According to literature, there is no solid evidence to show how religious region influences neighborhood walkability. After checking all the trips from the Utah Household Travel Survey in Salt Lake County, there are over 9000 trips for religious purposes, most of which are auto trips. Also, most of the religious regions are not closed to bus or light rail stations. Hence, religious region does not promote neighborhood walkability in Salt Lake City. Furthermore, the location of these religious regions also influences urban development and land-use planning in the surrounding areas. The commercial land-use and population density are examined in religious regions (by 800 meters buffer). Twenty-seven percent of religious regions are covered by commercial land-use, while the average value in Salt Lake County is 35%. Population density is also low in religious regions, the value of which is 106 households per square kilometer while the average value is 120. This result suggests that the religious regions are usually far from commercial land-use and have low population density, both of which lead to low walkability. Since religion is an important part of people's daily life in Salt Lake County, improving the neighborhood environment in religious regions would help promote walking.

Previous studies on the relationship between walkability and neighborhood environment rarely consider spatial dependence. However, based on the result of Moran's I test, spatial autocorrelation should not be ignored. A geographically weighted regression model is employed to test the effect of spatial heterogeneity on walkability in Salt Lake County. We map the coefficient estimations of GWR model in Figure 7.1. Figure 7.1 is a set of figures that present the coefficient estimations of dwelling density, retail floor area ratio, distance to worship, and education level. From Figure 7.1, we find that the influence of these four variables has significant geographic variations across northeastern and southwestern Salt Lake County. We can see that northeastern Salt Lake County is more sensitive to two land-use measures. This variation also corresponds to the cluster pattern of walkability. In the neighborhood with high walkability and population density, people's walking behavior is likely to be influenced by neighborhood design. Oppositely, the distance to worship influences the southwestern part more. Education level has more influence on people's walking behavior in the central and eastern part of Salt Lake County.

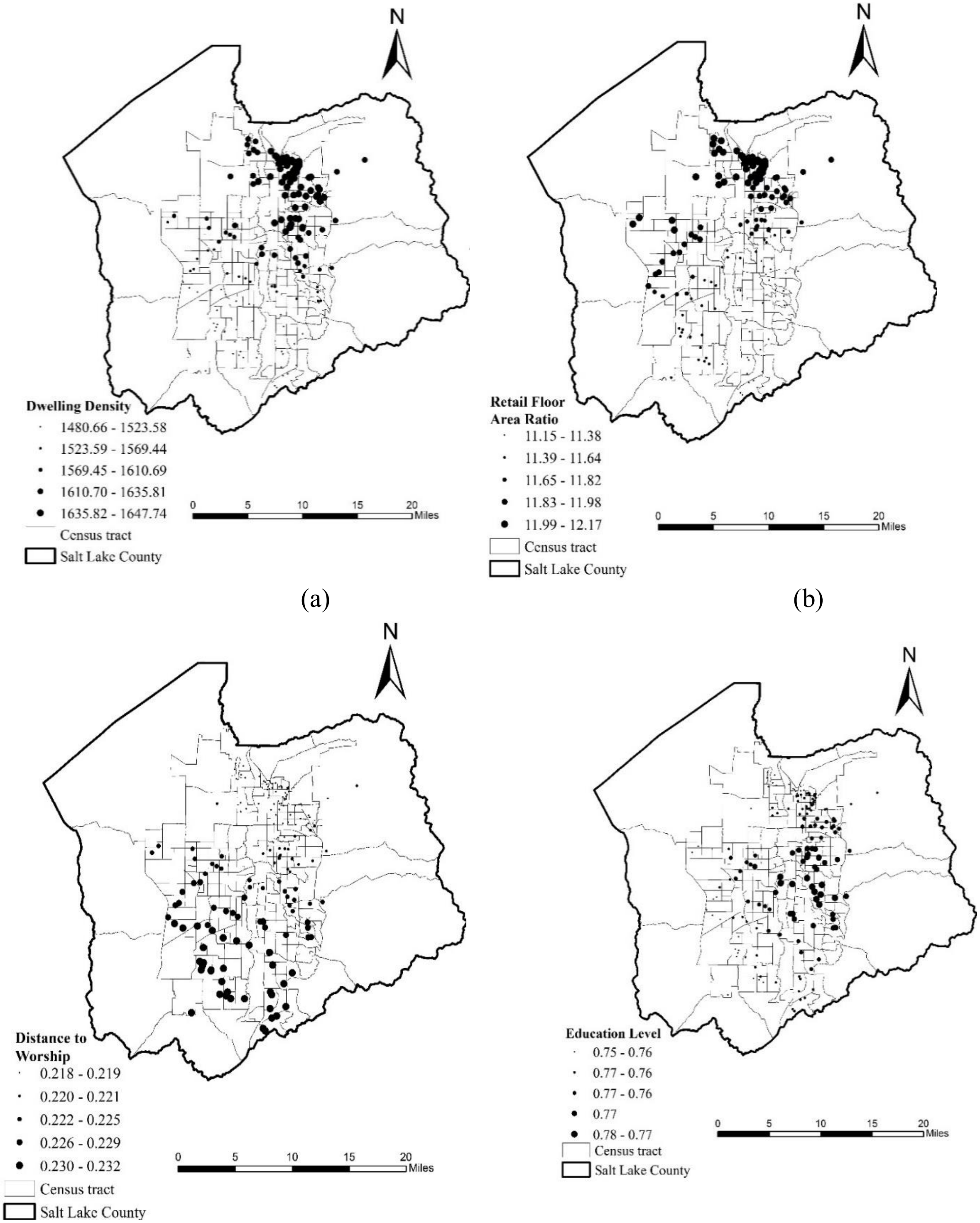

Figure 7.1 GWR Coefficient Estimation of Dwelling Density (a), Retail Floor Area Ratio (b), Distance to Worship (c), Education Level (d)

CHAPTER 8

CONCLUSION

Promoting PA can benefit people's physical and mental health and contribute to sustainable development in Salt Lake County where the obesity epidemic is getting more and more serious. Walking without any impending costs is regarded as the best moderate to vigorous PA. Based on previous research, walking is largely influenced by people's preference, neighborhood design, and sociodemographic status. The walkability index is a comprehensive evaluating system to measure people's walking behavior from neighborhood design.

In this thesis, PA is assessed by walkability index, sociodemographic status, accessibility to transportation and public facilities, and neighborhood safety. The effectiveness of walkability indices is tested at various geographic scales using linear regression models. The result suggests that the walkability index works within the neighborhood defined by a 1600-meter network buffer. Among four walkability indices, compact designs like dwelling density and retail floor area ratio are significantly related to PA. Both a nonspatial model and a spatial model are employed to examine the relationship between neighborhood amenity, sociodemographic status, neighborhood safety, and PA. The results show that sociodemographic status factors are the dominating determinants of PA. Besides, neighborhood environmental factors should not be overlooked. The distance to worship is associated with PA and improving neighborhood environments around religious regions is an option to improve walkability. Comparing results of the nonspatial model and spatial model, ignoring spatial factors would make the model result biased, and the spatial model is necessary to PA research. Furthermore, the latent variable analysis emphasizes the importance of the accessibility to public transportation in walkability research. Since many cities are developing TOD policy, the accessibility to public transportation should occupy a more prominent position in walkability research.

These findings will help us to better understand people's walking behavior and achieve the sustainable development of Salt Lake County. As many metropolitan regions in the United States are suffering from urban sprawl, compact urban design and TOD policy are required to promote walking. In future work, more urban evolution factors should be examined such as urban land expansion (Gao, Wei, Chen, & Yenneti, 2015) and the accessibility to more kinds of public facilities will be considered.

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